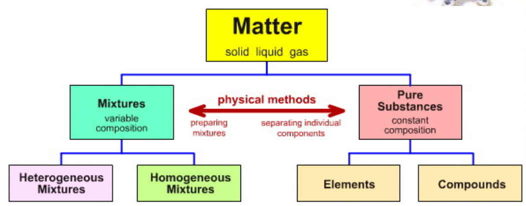
Chapter 8: Solutions and Their Properties

This salt mine in Goderich, Ontario is the largest in the world. It is situated on an ancient basin where a sea once existed.

The sea dried up, leaving large deposits of sodium chloride crystals. Salt is used for many purposes, including de-icing roads, softening water, and seasoning food.

Classification of Solutions



8.1 Classifying Solutions

A **solution** is a homogeneous mixture of two or more substances.

Homogeneous means that the mixture has a uniform composition throughout, even at the microscopic scale. Once a solution has been fully mixed, the substances in it remain evenly distributed throughout the solution.

This cup contains two solutions. The coffee is an aqueous solution, and the stainless steel spoon is a solution of metals.

Solutions

The substance that is present in the greatest amount in a solution is called the **solvent**. Any other substances in the solution are **solutes**. Solutions that contain water, such as coffee and tea, are called **aqueous solutions**.

In a cup of coffee, the water is the solvent and the substances from the coffee beans are the solutes. A solution can be formed from a solvent and a solute in any state. Refer to the next three slides for all nine examples.

Solutions in Different States of Matter

Solid Dissolved in Solid	Solid Dissolved in Liquid	Solid Dissolved in Gas
The structural steel that is used to construct buildings usually contains from 0.2 to 1.5% carbon dissolved in iron.	On average, 1 L of seawater contains about 19 g of chloride ions, 11 g of sodium ions, and 5 g of other solutes, including magnesium, sulfate, calcium, and potassium ions.	Molecules of naphthalene or paradichlorobenzene separate from the surface of a mothball to form a solution with air. The vapour from a mothball is toxic to moths and many other organisms.
		

Solutions in Different States of Matter

Liquid Dissolved in Solid	Liquid Dissolved in Liquid	Liquid Dissolved in Gas
Liquid mineral spirits or liquid toluene are dissolved in solid wax to make the wax easier to apply.	Antifreeze liquids are mixed with water in car radiators to form solutions with low freezing points.	Humidity results from water dissolving in the air. A hygrometer is a tool that measures humidity.
		

Solutions in Different States of Matter

Gas Dissolved in Solid	Gas Dissolved in Liquid	Gas Dissolved in Gas
Most ice contains a small amount of dissolved air.	When a bottle of a carbonated beverage is opened, some of the dissolved carbon dioxide bubbles out of the solution.	Natural gas is a solution of methane gas with ethane, nitrogen, carbon dioxide, and other gases dissolved in it.



Solubility

Substances vary in how readily they will dissolve in a solvent. **Solubility** is defined in terms of the maximum amount of solute that will dissolve in a given quantity of solvent at a specific temperature.

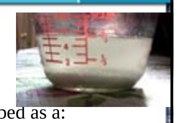
At 20ºC:
- sodium chloride is soluble in water (35.9 g/100 mL)
- calcium hydroxide is sparingly soluble in water (0.183 g/100 mL)
- calcium carbonate is insoluble in water (about 0.005 g/100 mL).

Solubility and Saturation

A solute is described as:

- *soluble* if more than 1 g is dissolved in 100 mL of solvent
- *slightly* or *sparingly soluble* if between 0.1 g and 1 g is dissolved in 100 mL of solvent
- *insoluble* if less than 0.1 g is dissolved in 100 mL of solvent

Levels of Saturation



At a specific temperature, a solution is described as a:

- **saturated solution** if no more solute can be dissolved
- **unsaturated solution** if more of the same solute can be dissolved
- **supersaturated solution** if it contains more dissolved solute than a saturated solution at the same temperature. This usually occurs when a temperature change occurs. Super-saturated solutions are unstable, and a disturbance can precipitate out the excess solute.

Section 8.1 Review

Section 8.1 | Classifying Solutions

Every solution is a homogeneous mixture, with a composition that can be described both qualitatively and quantitatively.

KEY TERMS

aqueous solution	solution
saturated solution	solvent
solubility	supersaturated solution
solute	unsaturated solution

KEY CONCEPTS

- A solution is a completely homogeneous mixture. It can be formed from a solute and a solvent in any initial state: solid, liquid, or gas.
- The solvent in a solution is the substance present in the greatest amount. Solutes are anything dissolved in a solvent.
- The solubility of a substance is stated in terms of the maximum amount of solute that dissolves in a given quantity of solvent at a specific temperature.
- A solution can be classified as unsaturated, saturated, or supersaturated, depending on the amount of dissolved solute per unit volume of solution.

8.2 Factors That Affect Solubility and Rate of Dissolving

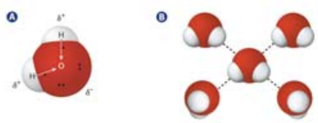
Solubility can be explained in terms of the forces that act between the particles of the substances in solutions. The formation of most solutions depends on the relative strength of three categories of forces:

- forces that attract particles of the solute to each other
- forces that attract particles of the solute to particles of the solvent
- forces that attract particles of the solvent to each other

Solubility in Water

Click here for STSE

The polar nature of water molecules enables water to dissolve a wide range of solutes. Recall that oxygen atoms are more electronegative than hydrogen atoms, and the O-H bonds in a water molecule are polar. The V-shape of the water molecule results in an overall polarity to the molecule (a dipole) that allows **hydrogen bonding** to occur between molecules. Hydrogen bonding is a type of dipole-dipole attraction between molecules where the hydrogen atom on one molecule will attract a small electronegative atom on another molecule.

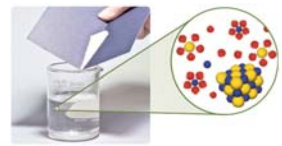


(A) The hydrogen atoms in a water molecule have a net positive charge, whereas the oxygen atom has a net negative charge. **(B)** The attraction between the positive and negative charges on the polarized bonds in water molecules creates hydrogen bonds between adjacent molecules. The hydrogen bonds are shown by the dashed lines.

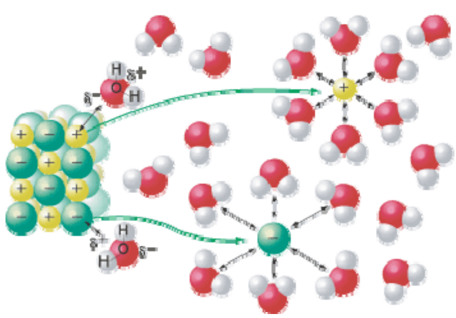
Solubility of Ionic Compounds in Water

Most ionic compounds are soluble in water. The dissolving process occurs in two steps.

- Electrical attraction between the polar water molecules and the ions pulls ions from the surface of the solute.
- Polar water molecules surround separated ions in a process called **hydration**, and ions disperse uniformly in solution.

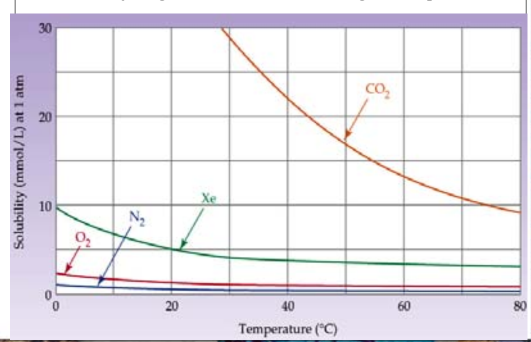


When a soluble ionic compound, such as sodium chloride, is added to water, the ions separate and several water molecules surround each ion. During hydration, water molecules (shown in red) surround sodium ions (shown in blue) and chloride ions (shown in yellow).



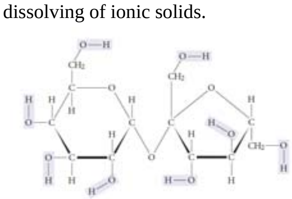
Temperature & the Solubility of Gases

The solubility of gases DECREASES at higher temperatures



Solubility of Polar Molecular Compounds in Water

A molecular compound that is polar (a dipole) is held together by relatively weak dipole-dipole attractions between molecules. Table sugar (sucrose) is an example of such a compound. These compounds dissolve in the same two steps described for the dissolving of ionic solids.

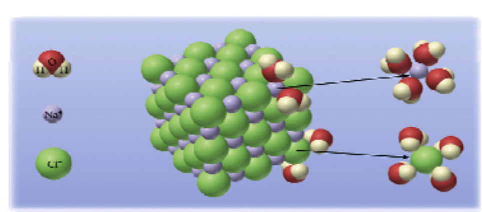


The molecular structure of sucrose includes eight polar -OH groups.

Dissolution of Solid Solute

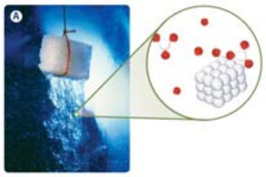
What are the driving forces which cause solutes to dissolve to form solutions?

1. **Covalent solutes** dissolve by H-bonding to water or by London Dispersion Forces.
2. **Ionic solutes** dissolve by dissociation into their ions.



Solubility of Polar Molecular Compounds in Water

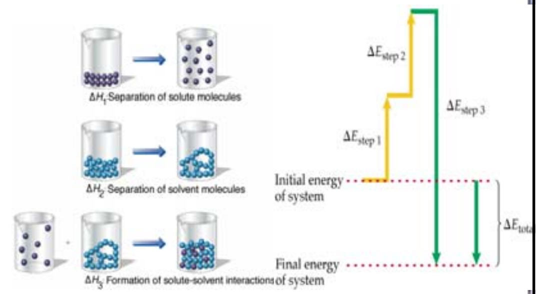
For compounds of this type, the dipole-dipole attraction between polar solute molecules is weaker than the hydrogen bonds between the solute molecules and the water molecules.



(A) Sucrose is a polar molecule so it dissolves readily in water. Sucrose molecules (shown in white) are hydrated by water molecules (shown in red).

Dissolution at the molecular level?

- **Consider the dissolution of NaOH in H_2O**



Insolubility of Non-Polar Compounds in Water

Non-polar compounds do not dissolve in water. The attractions between molecules of a non-polar molecular compound and water are too weak to break the hydrogen bonds between the water molecules.

(B) The non-polar molecules in vegetable oil are insoluble in water.

Conductivity of Aqueous Solutions

As shown in the figure, solutions of ionic compounds can conduct an electric current, but solutions of most molecular compounds conduct little or no current.

A conductivity tester can distinguish between ionic and most molecular substances in aqueous solution.

Why is this the case? An ionic compound dissociates into separate ions when it dissolves. The separate ions can carry charge to electrodes immersed in the solution. Most molecular compounds remain intact when they dissolve. The intact molecules are neutral and are not attracted to positive or negative electrodes.

Predicting Whether an Ionic Compound is Soluble in Water

Ionic compounds are held together by the attraction between ions with opposite charges. The solubility of an ionic compound in water depends on the strength of that attraction. The force of attraction depends on:

- the amount of charge on each ion
- the size of each ion

As shown in the table on the next slide:

- the greater the charge on each ion, the less soluble the compound
- as ion size increases, so does solubility

Predicting Whether an Ionic Compound is Soluble in Water

Anion Symbol and Relative Ionic Radius	Formula of Compound	Solubility at 25°C (g/100 mL)
O^{2-}	MgO	0.0006
F^-	MgF_2	0.008
Cl^-	$MgCl_2$	54
Br^-	$MgBr_2$	101
I^-	MgI_2	148

Effect of ion charge

Effect of ion size

Solubility Guidelines for Ionic Compounds

1. The hydrogen ion, ammonium ion, and all Group 1 (alkali metal) ions form soluble compounds with nearly all anions.
2. Nitrate and acetate ions form soluble compounds with nearly all cations.
3. Chloride, bromide, and iodide ions form compounds that have low solubility with silver, lead(II), mercury(I), copper(I), and thallium cations only.
4. The fluoride ion forms compounds that have low solubility with magnesium, calcium, barium, and lead(II) cations only.

Continued…

Solubility Guidelines for Ionic Compounds

5. The sulfate ion forms compounds that have low solubility with calcium, strontium, barium, and lead(II) cations only.
6. The sulfide ion forms soluble compounds with only the ions listed in guideline 1 and the Group 2 cations.
7. The hydroxide ion forms soluble compounds with only the cations listed in guideline 1, as well as strontium, barium, and thallium cations.
8. Phosphate, carbonate, and sulfite ions form compounds that have low solubility with all cations except those listed in guideline 1.

Solubility of Common Ionic Compounds in Water

	Anion +	Cation →	Solubility of Compound*
1.	Most	Alkali metal ions: Li^+, K^+, Rb^+, Cs^+, Fr^+	Soluble
	Most	hydrogen ion, H^+	Soluble
	Most	ammonium ion, NH_4^+	Soluble
2.	nitrate, NO_3^-	Most	Soluble
	ethanoate (acetate), CH_3COO^-	Ag^+	Low solubility
		Most others	Soluble
3.	chloride, Cl^- bromide, Br^- iodide, I^-	Ag^+, Pb^{2+}, Hg_2^{2+}, Cu^+, Tl^+	Low solubility
		All others	Soluble
4.	fluoride, F^-	Mg^{2+}, Ca^{2+}, Ba^{2+}, Pb^{2+}	Low solubility
		Most others	Soluble

Continued…

Solubility of Common Ionic Compounds in Water

	Anion +	Cation →	Solubility of Compound*
5.	sulfate, SO_4^{2-}	Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}	Low solubility
		All others	Soluble
6.	sulfide, S^{2-}	Alkali ions and H^+, NH_4^+, Be^{2+}, Mg^{2+}, Ca^{2+}, Sr^{2+}, Ba^{2+}	Soluble
		All others	Low solubility
7.	hydroxide, OH^-	Alkali ions and H^+, NH_4^+, Sr^{2+}, Ba^{2+}, Tl^+	Soluble
		All others	Low solubility
8.	phosphate, PO_4^{3-} carbonate, CO_3^{2-} sulfite, SO_3^{2-}	Alkali ions and H^+, NH_4^+	Soluble
		All others	Low solubility

*Compounds listed as soluble have solubilities of at least 1 g/100 mL of water at 25°C and 100 kPa.

Predicting Whether a Molecular Compound is Soluble in Water

Size affects the solubility of a molecular compound. Specifically, the proportions of polar and non-polar regions of the molecule dictate the solubility.

Increasing size of non-polar portion of molecule →

Name of Compound	Methanol	Ethanol	Propanol	Butanol	Pentanol
Chemical Formula	CH_3OH	CH_3CH_2OH	$CH_3CH_2CH_2OH$	$CH_3(CH_2)_3OH$	$CH_3(CH_2)_4OH$
Solubility at 25°C and 100 kPa	Soluble	Soluble	Soluble	9 g/100 mL	3 g/100 mL

"Like Dissolves Like"

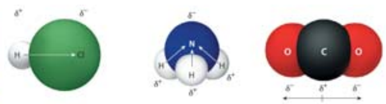
The force of attraction between a non-polar molecule and a water molecule is weaker than the hydrogen bonding between water molecules. Therefore, most non-polar molecules are insoluble in water. However, non-polar solvents can dissolve non-polar molecules because the forces of attraction between the solute and solvent molecules are similar.

Thus, polar solvents tend to dissolve ionic and polar molecules, and non-polar solvents tend to dissolve non-polar molecules. This can also explain why some gases dissolve in water, and some do not.

Continued…

"Like Dissolves Like"

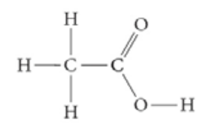
		SOLUTE	
		Polar or Ionic	Non-polar
SOLVENT	Polar	Usually soluble	Usually insoluble
	Non-polar	Usually insoluble	Usually soluble



The bonds and arrangement of atoms in hydrogen chloride and ammonia cause the molecules to be polar. However, carbon dioxide is non-polar because both ends of the molecule have a partial negative charge.

Molecules That Have Both Polar and Non-Polar Components

Acetic acid, soap, and detergent can dissolve in both polar and non-polar solvents because they have both polar and non-polar bonds within their molecular structure.



The molecular structure of acetic acid shows its polar O-H bond and its non-polar $-CH_3$ group.

Temperature and Solubility

A graph that shows the relationship between the solubility of a solute and the temperature of the solvent is called a solubility curve.

For most ionic solids, solubility increases as the temperature increases.

At higher temperatures, solvent particles have more energy, resulting in more frequent and energetic collisions with solute particles.

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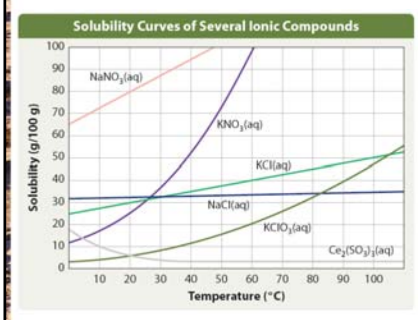
Temperature and Solubility

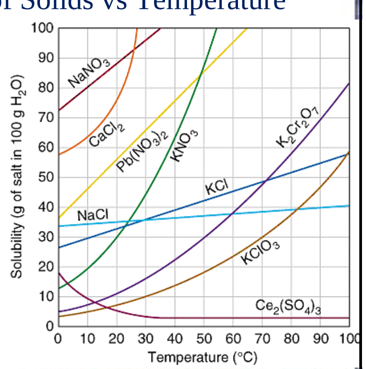


The solubility of most ionic substances in water increases with temperature. In this graph, the solubility is given in grams of solute per 100 g of *solvent*. This is different from other expressions of solubility, which are given in grams of solute per 100 mL of *solution*.

Solubilities of Solids vs Temperature

Solubilities of several ionic solid as a function of temperature. MOST salts have greater solubility in hot water.

A few salts have negative heat of solution, (exothermic process) and they become less soluble with increasing temperature.



Temperature and Solubility (liquid in a liquid, gas in a gas)

Temperature change has little effect on the solubility of one liquid in another or one gas in another.

For two samples of a liquid or two samples of a gas at the same temperature, there is little or no energy exchanged between particles when they are mixed.

Temperature and Solubility (gas in a liquid)

The solubility of a gas in a liquid decreases as the temperature increases.

There is a large change in the kinetic energy of gas molecules when they enter or leave a solution. Increasing the temperature of a solution increases the kinetic energy of the molecules, allowing them to escape.

Example: A carbonated drink goes flat (loses dissolved carbon dioxide) faster at room temperature than it does in a refrigerator.

Environmental Effects of Increased Temperatures

When water from nearby bodies of water is used to cool hydroelectric plants or support manufacturing processes and then returned to the body of water, the resulting thermal pollution adversely affects the environment.

The transfer of waste heat to a body of water can decrease the concentration of oxygen that is dissolved in the water.

Continued…

Environmental Effects of Increased Temperatures

Aquatic organisms, including animals, need the oxygen that is dissolved in the water they live in. Water returned to the environment at a higher temperature warms the body of water.

The higher water temperature means there is less dissolved oxygen. The aquatic organisms become more susceptible to disease and may die.

Pressure and Solubility (gas in a liquid)

The solubility of a gas in a liquid is directly proportional to the pressure of that same particular gas above the liquid.

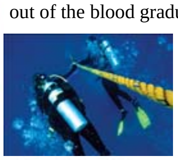
Since pressure affects the solubility of a gas in a liquid, the solubility of a particular substance is stated at standard ambient temperature (25ºC) and pressure (100 kPa) or SATP.

(A) A soft drink is bottled with a high pressure of carbon dioxide to increase the solubility of this gas in the drink. **(B)** The pressure of carbon dioxide in the atmosphere is much lower than the pressure in the bottle, which causes the gas to come out of solution.

Pressure, Solubility and Scuba Diving

Scuba divers breathe compressed air. Water pressure increases as a diver descends to greater depths. A valve system is needed to automatically regulate the pressure of the air the diver breathes to match the pressure of the surrounding water.

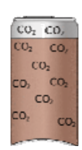
Since the pressure is greater under water, more of the gases, especially nitrogen, are dissolved in the diver's blood. This means a diver must surface slowly to allow the dissolved nitrogen to come out of the blood gradually.



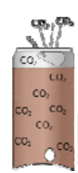
If not, the painful (and potentially fatal) "bends" can occur as nitrogen forms bubbles in the blood.

Scuba divers wear gas tanks during their dives. The tanks contain air at very high pressures.

EFFECTS OF PRESSURE



CLOSED CAN
Area of high pressure



OPEN POP TAB
-pop goes flat
-pressure lessens

POP GOES "FLAT"

Factors That Affect Rate of Dissolving

The **rate of dissolving** is a measure of how quickly a solute dissolves in a solvent. Three main factors increase the rate of dissolving by increasing the rate of collisions between the solute particles and the solvent particles.

- agitation or mixing (stirring)
- temperature increase
- increased surface area of the solute

Solids are ground into coarse grains or powder to increase the rate of dissolving.

Section 8.2 Review

Section 8.2 | Factors That Affect Solubility and Rate of Dissolving

The key factor that determines whether a solute is soluble in a solvent is the nature of the bonds within and between the solute and the solvent

KEY TERMS

hydration
hydrogen bonding
rate of dissolving

KEY CONCEPTS

- Intermolecular forces affect solubility.
- Water is a good solvent because it can dissolve a wide range of solutes.
- Ionic compounds that contain ions with relatively large charges or small radii tend to be insoluble in water.
- Polar solvents tend to dissolve ionic and polar molecules. Non-polar solvents tend to dissolve non-polar molecules.
- Solubility is affected by temperature and pressure.
- The rate of dissolving a solid solute in a liquid solvent is affected by temperature, the surface area of the solute, and agitation.